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Kevin L. Chesnutwood

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Kevin L. Chesnutwood
Manufacturing Metrology Division
Manufacturing Engineering Laboratory
National Institute of Standards and Technology
Gaithersburg, MD 20899

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This paper focuses on the redesign of the snubber system that is used in the 112.5 kN (25.3 klf) dead weight machine located at the National Institute of Standards and Technology in Gaithersburg, Maryland. Obstacles that were overcome pertaining to the original machine design and problems encountered with the initial air cylinder snubber approach are identified. The approach, improvements, and limitations to using the current air bag snubber system are examined.

1. Introduction

The National Institute of Standards and Technology maintains six dead weight machines ranging from 2.2 kN (505 lbf) to 4.448 MN (1000 klf) which act as primary force standards for calibrating elastic force-measuring devices.[1] Program additions, such as the National Type Evaluation Program (NTEP), and changes in customer demands and testing standards since the machines were built 35 plus years ago have required that three of the NIST deadweight machines either be modified or operated in a manner inconsistent with the original machine design in order to meet the current needs and standards. Of the six dead weight machine designs, the 2.2 kN (505 lbf), 27.1 kN (6.1 klf) and the 112.5 kN (25.3 klf) machines were designed for return-to-zero loading sequences. Section 2 will identify why having to use return-to-zero loading sequences creates problems with current customer demands. Section 3 will then examine the first attempt at a solution using an air cylinder actuated snubber and the problems associated with this system. Following in Section 4 will be a description and analysis of the current design that incorporates the use of small air bags. The advantages of this improved system, as well as problem areas, are covered in Section 5 along with the steps taken to improve and/or eliminate the trouble spots. Finally, Section 6 will conclude the paper by highlighting the improvements achieved by using the air bag snubber system.

2. Obstacles with the Original 112.5 kN Dead Weight Machine Design

As mentioned earlier, of the six dead weight machine designs, the 2.2 kN, 27.1 kN and the 112.5 kN machines were designed for return-to-zero loading sequences. Return-to-zero loading requires that when moving from one measurement point to the next, the operator is required to unload the unit under test from the weight frame, change the weight selection, and then reload the weight frame onto the unit under test. In this configuration, an ideal condition is achieved by having the shaft of the dead weight machine restrained at all times while weights are being changed (unit under test unloaded). The restrained condition assures a stable measurement environment and proper alignment for loading and unloading weights onto the shaft. Figure 1a shows a CAD model of the 112.5 kN dead weight machine and the shaft restraint on the original design. Figure 1b shows a photo of the lower portion (below laboratory level) of 112.5 kN dead weight machine.

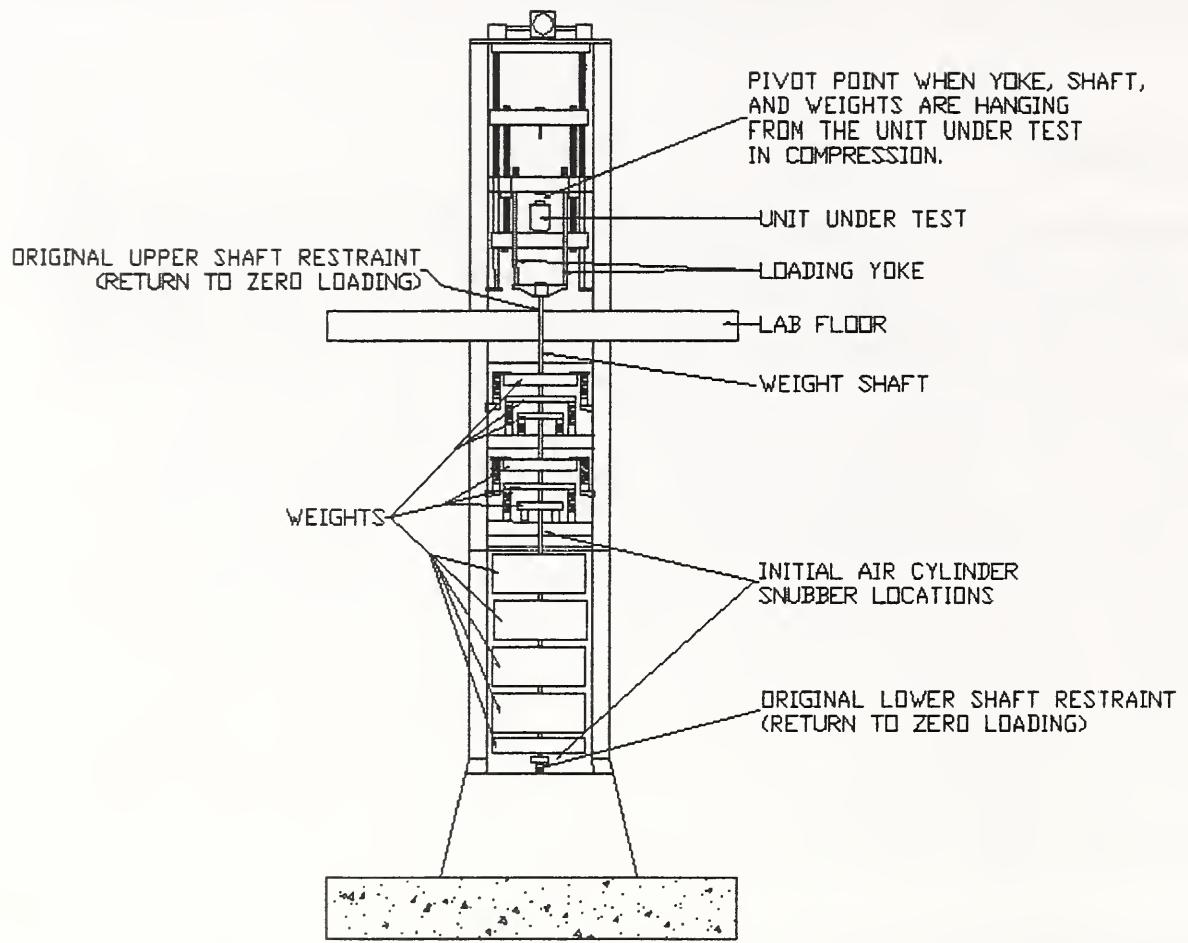


FIGURE 1a
CAD model of the 112.5 kN (25.3 klf) dead weight machine

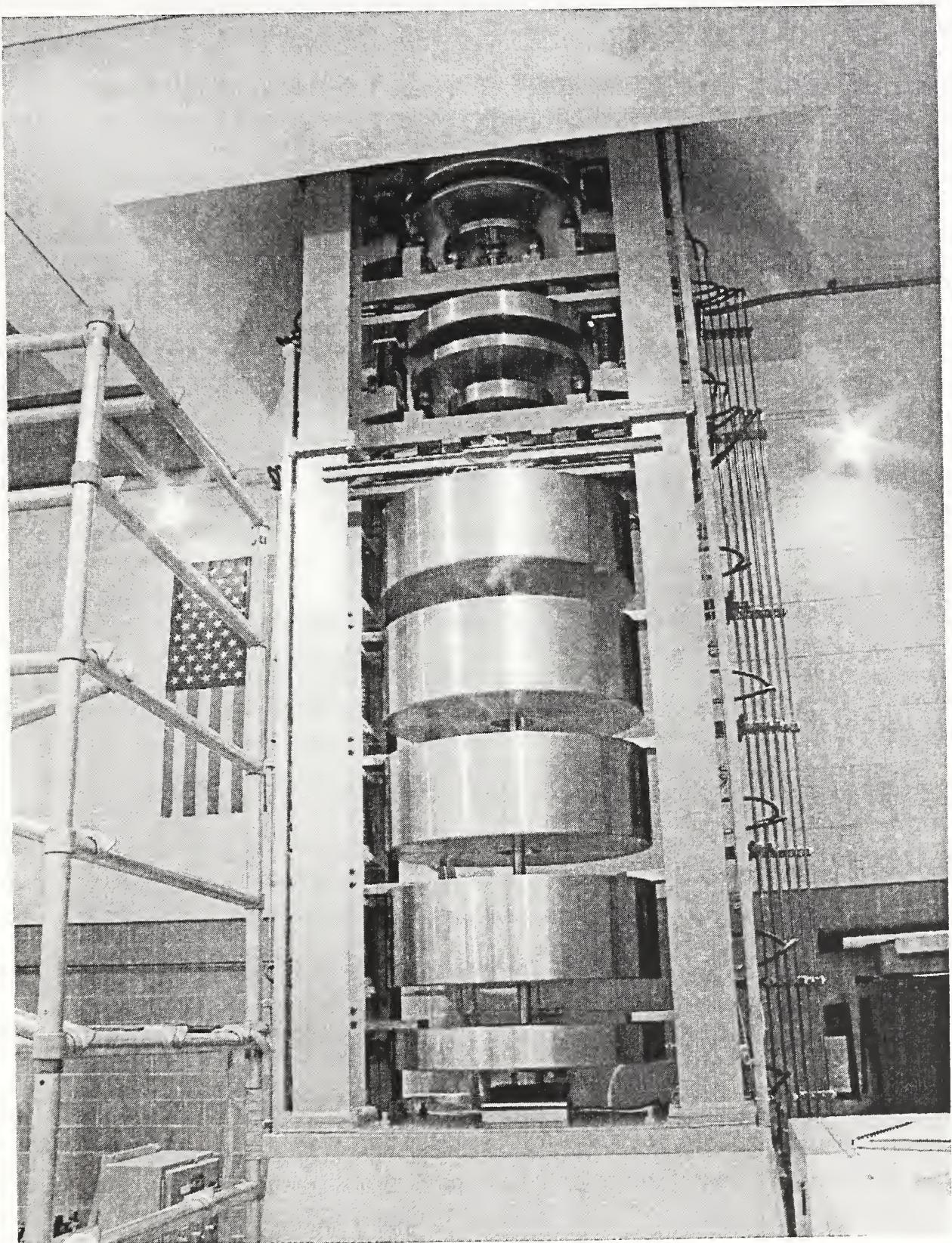


FIGURE 1b
Photo of the main weight stack of the 112.5 kN (25.3 klbf) dead weight machine

However, this arrangement causes problems when excursion loading is required. Excursion loading allows the operator to go directly from one measurement point to the next without unloading the unit under test in between those points. Although excursion loading is not necessary for taking ascending data, in many instances it is the preferred method because it allows for more efficient loading sequences. Although most current standards such as American Society for Testing and Materials (ASTM) E74-02 [2] allow for return-to-zero loading when ascending data is being taken, prototype testing protocols such as National Conference of Weights and Measures (NCWM) Publication 14 [3] and Organisation Internationale de Métrologie Légale (OIML) R 60 [4] do require excursion loading as part of the testing protocol. In addition, all hysteresis data has to be monotonically descending from a higher force point with no return to zero allowed between measurement points. Therefore, in order to change measurement points with the unit under test in a loaded condition, a technique for restraining the shaft while still in a loaded condition needed to be devised. The restraint of the shaft at load would thus allow excursion and hysteresis loading while keeping a stable measurement environment while changing weights. Otherwise, if weights are loaded or unloaded without restraining the shaft, the unrestrained shaft (hanging from the unit under test) starts swinging while the weights are being loaded or unloaded. The swinging not only hampers alignment of the weight lifting assemblies but also would continue throughout the measurement process. In order to prevent potentially poor measurement results, the operator was required to damp the swing of the weight stack manually by hand or wait until it damped naturally before taking measurements. The longer waiting times increase difficulty in adhering to the timing requirements set forth in the standards listed earlier in this section. Additionally, the swinging could potentially cause wear problems on the loading interfaces while changing weights due to not having proper alignment of the shaft and the weight seats as the system is in motion.

3. Air Cylinder Snubber Design and Associated Problems

Nearly 15 years ago and knowing of the problems and parameters discussed in section 2, the air cylinder snubber design was developed for the 112.5 kN dead weight machine. The air cylinder design incorporated a pair of air cylinders acting in opposing horizontal directions with an attachment (gripper) on each cylinder. This method attempted to stabilize the shaft while changing weights and while the unit under test was still in a loaded condition. The gripper was machined to fit half way around the shaft of the dead weight machine. When engaged, the cylinder assemblies would extend the grippers from each direction and enclose and restrain the shaft, holding it in place while weight changes occurred. Figure 2 shows a CAD drawing of this original setup. One pair was located at the bottom of the machine while another pair was located about half way up the machine. The upper pair was directionally offset 90° to ensure stability in both directions (refer to Figure 1a for locations). The cylinder assemblies were designed to engage the grippers around the shaft at precisely the centerline of the dead weight machine each and every time. This setup allowed for ideal weight changing conditions because it maintained perfect alignment between the centerline of the shaft and the weights.

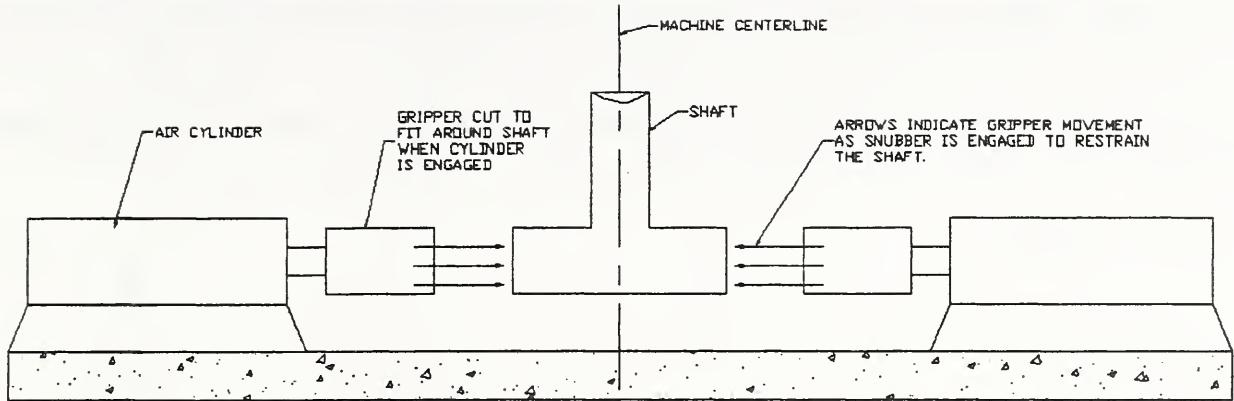


FIGURE 2
CAD drawing of the original air cylinder snubber design.

However, some unexpected difficulties arose. The first problem involved getting the grippers to apply and release from the shaft in a synchronized manner. The air cylinders assemblies were rather crude devices with very little ability for smooth, precise control. The cylinder assemblies would rarely release in unison. The lack of synchronization sometimes caused a slight push on the weight shaft upon release of the snubbers, resulting in a pendulum type swing of the entire weight stack. The resulting swing was similar in effect to changing weights at load without using a snubber at all and had to be dealt with in the same way.

In an attempt to overcome this problem, several synchronization mechanisms were tested. The synchronization attempts included adjusting the air pressure individually to each cylinder and also using fluid in a closed loop system to help push or pull the grippers in unison. As one piston would extend, it would force fluid into the other cylinder to help extend the opposing piston and vice versa for the retraction of the pistons. The theory was that if one gripper lagged behind slightly, the push of the fluid coming from the other cylinder would help equalize the movements. Ultimately, a mechanical cable/pulley system using the same theory worked best at getting the cylinders to move together at coordinated times. As one gripper assembly would extend or retract, it would help extend or retract the other gripper assembly by means of a physically connected cable between the grippers that looped around a pulley to impart the force in the proper direction. This would physically force the gripper assemblies to work in unison. However, the cable/pulley system never completely solved the problem, because there was another factor playing into the interaction. As mentioned earlier, the cylinders always located the shaft at the centerline of the weight stack. Initially, center line alignment was thought to be the best arrangement for the sole reason of weight alignment

while changing weights. However, after using the system for several years, it was determined that it would be better to restrain the shaft at its natural hanging position rather than forcing it to the centerline. The reason for this determination was that the shaft does not always hang in a perfect centerline position due to loading interfaces between the unit under test and the loading yoke of the dead weight machine. Therefore, when the cylinders would release (no matter how perfect the synchronization), the shaft would try to return to its natural hanging position causing a pendulum like swing. The amplitude would vary between 1 cm and 2 cm (0.39 inch and 0.78 inch) and the period would be approximately between 3 s and 6 s. When this happened, any measurement on the unit under test had to be delayed until the swinging of the shaft damped naturally or was damped manually.

The second problem associated with the air cylinder snubbers was that they were oversized and applied more force to the shaft than was necessary while they were engaged and weights were being changed. The problem of too much force on the shaft can be an issue when taking hysteresis measurements. When descending from a higher force point to a lower force point, one can never let the force applied to the unit under test fall below that of the lower test point. For example, to go from 44482 N (10000 lbf) down to 22241 N (5000 lbf), the force cannot drop to say 13345 N (3000 lbf) and then return to 222411 N (5000 lbf), one must stay above 22241 N (5000 lbf) at all times. The weight sequences must be chosen accordingly to always ensure a monotonically decreasing force application. Testing of the air cylinder piston snubbers determined that they removed between 135 N (30.3 lbf) and 178 N (40.0 lbf) from the unit under test while engaged during weight changes. Therefore, when doing hysteresis measurements, the unit under test would experience a slight decrease in force below the value that the unit would experience after the snubbers were released. Attempts were made to lessen the engaged force by decreasing the air pressure in the cylinders, but they would not operate properly at pressures below their normal operating pressure of 345 kPa (50 psi). Numerous tests were completed at the time comparing hysteresis data taken using the snubbers and data taken manually with no snubbers (damping naturally or manually). The resulting data showed that when using the snubbers, the minor decrease in force below the value that the device would see after the snubbers were released did not show any difference from that taken without the snubbers. Although the force the snubbers removed was determined to be irrelevant, it was agreed that this force could be substantially decreased or ideally eliminated to incorporate a closer representation of an ideal condition.

The third problem with the air cylinder snubber assembly was the fact that it provided no restraint on the weight shaft above the midpoint of the machine. Therefore, in some flexible tension setups, the shaft and loading yoke would oscillate at the upper end of the machine even while it was restrained at the lower end. This caused or compounded problems similar to those mentioned earlier regarding weight swing.

4. Solution Using Air Bag Systems

Another attempt to cure the aforementioned problems discussed in Sections 2 and 3 was undertaken starting in the Spring of 2002. In order to overcome all of the problems and still provide a restrained weight shaft for changing weights at load, a system employing air bags [5] was tested and determined to be an effective solution. Subsequently, the air bag system was installed on the dead weight machine and is in use today. The system was low cost (under \$3000.00 in materials) and requires little maintenance or adjustment.

Rather than apply a force perpendicular to the weight shaft like the air cylinder snubbers, the first stage air bag assembly works from the underside of the weight shaft as shown in Figure 3a and the photo in Figure 3b. When changing measurement points, the air bag inflates pushing a piece of high-density foam in contact with the bottom of the weight shaft, slightly compressing the foam. The foam does not force the shaft to centerline, but instead stabilizes it in its natural hanging position. Also, since the foam does not form a rigid bond with the shaft, the shaft (being held only with friction with the foam) is free to hang in its natural state even if that natural hanging state changes slightly as the weights are applied or removed. However, the friction between the foam and the shaft is great enough to quickly damp any pendulum type swings that were discussed earlier. Therefore, when the air bag is slowly retracted, it releases the shaft smoothly in its natural hanging position and thus imparting little or no swing to the weight stack (under 0.5 cm (0.20 inch) amplitude). The air bag is retracted using spring action to force the air out of the air bag bladder at a controlled rate. Since the air bag is a single actuator, the synchronization problems were also eliminated.

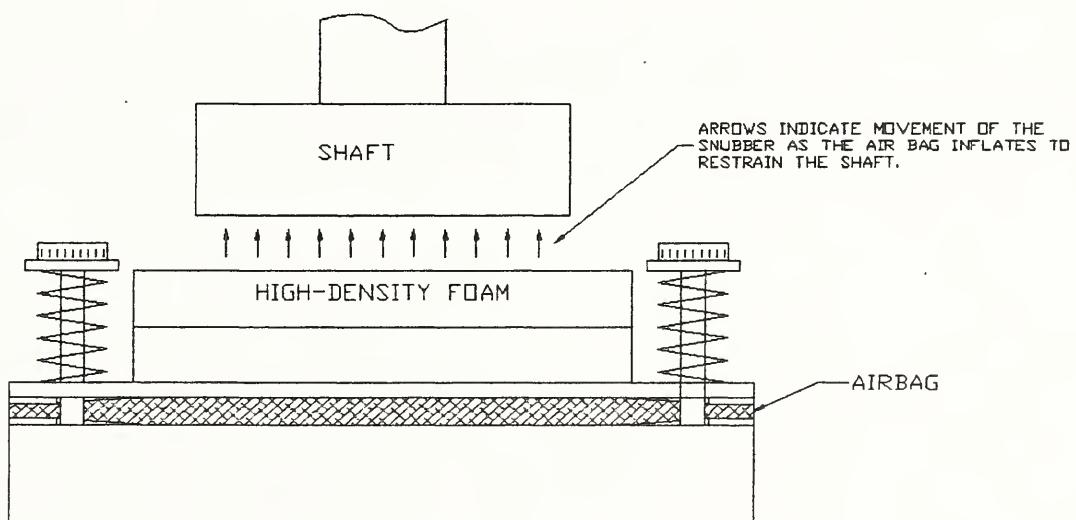


FIGURE 3a
CAD Drawing of First Stage Air Bag Snubber

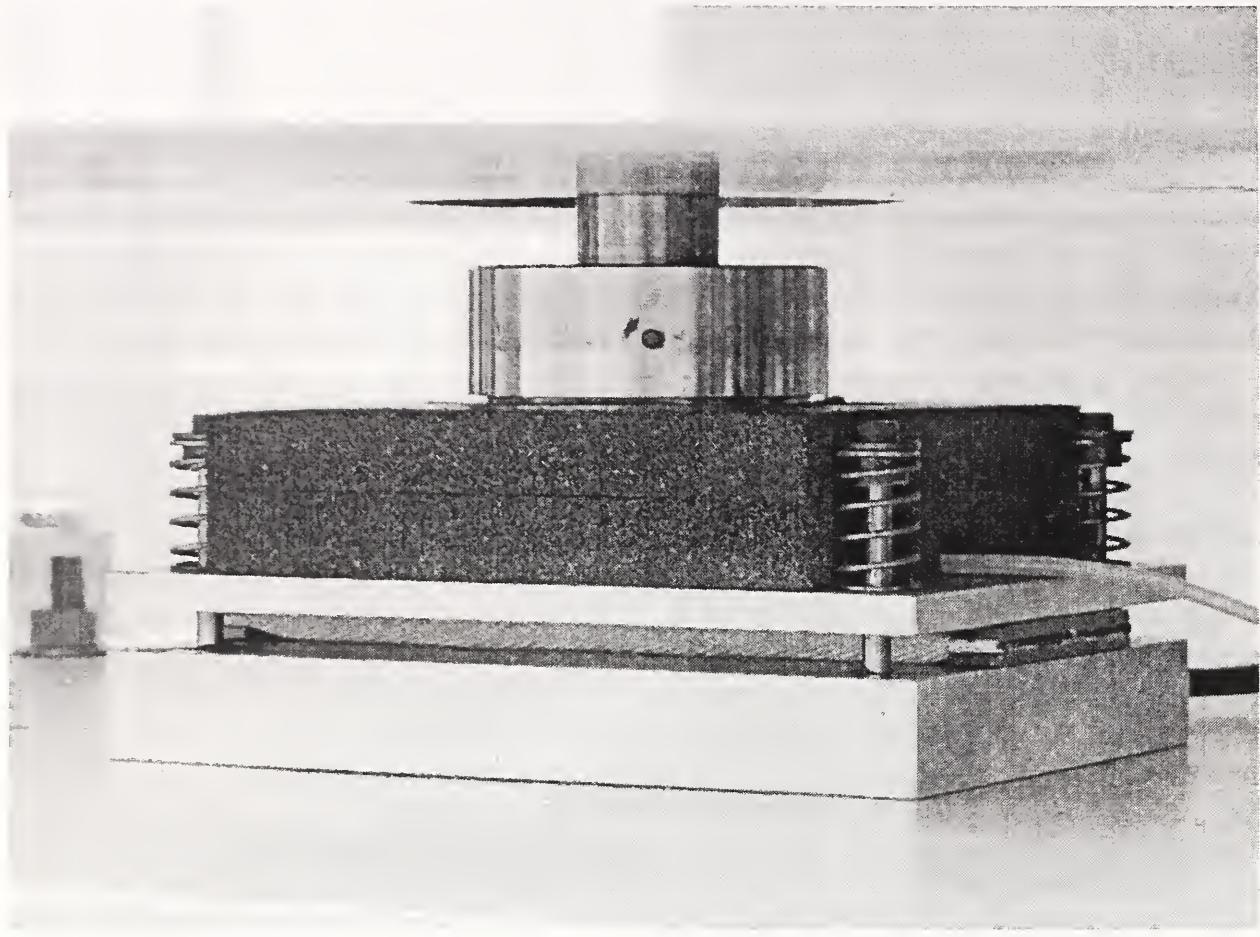


FIGURE 3b
Photo of First Stage Air Bag Snubber

The second stage of the air bag system can be seen in Figure 4 and is placed at the yoke of the dead weight machine. At this location, the air bags are engaged directly against the loading yoke. When engaged simultaneously with the lower airbag (stage 1), these two upper air bags inflate, push out against the yoke, and form a pillow-type damper against the yoke assembly. The air bags effectively damp any swing or oscillation of the yoke assembly and help to restrain the entire weight shaft while changing weights. The force applied by the airbags is minimal and they operate between 68.9 kPa (10 psi) and 137.9 kPa (20 psi). Synchronization and "shaft push" are not a problem because the air bags operate from the same pressure line, resulting in the same force being applied at all times and equal deflation rates between the bags. The overall force that the combined air bags (upper and lower) remove from the unit under test while engaged ranges from 44 N (10 lbf) to 66 N (15 lbf). Although not totally eliminated, the force is decreased by a factor of two when compared to the initial air cylinder snubber system.

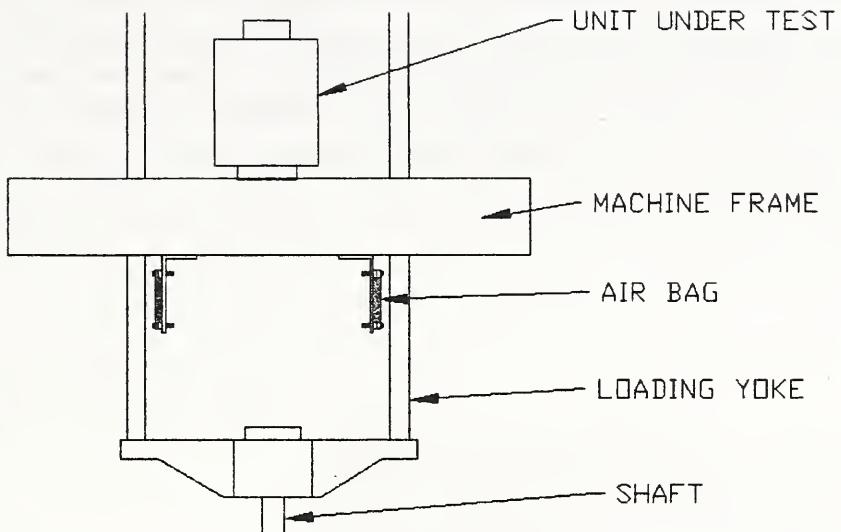


FIGURE 4
CAD Model of Air Bag Snubber Second Stage

5. Obstacles with the Air Bag System

Although the new air bag system showed improvement in comparison to the air cylinder piston snubber system, there were still a few minor problems and limitations that had to be overcome and/or addressed. One, in order to fit the new air bag systems into the machine, the original shaft restraint had to be removed. Therefore, when the unit under test was unloaded, there was now no restraint to hold the shaft while the weights were being changed. This problem was corrected by incorporating a software change into the current operating system that allows for only the lower air bag to engage while the machine is unloading, thus holding the shaft in place as did the original restraint. The loading yoke is already restrained when the unit under test is unloaded and therefore does not require the upper air bags to be engaged under this circumstance. Additionally, this eliminates the potential problem of the upper snubbers being engaged against a moving yoke assembly.

As mentioned previously, the new air bag system still removes a small amount of force from the unit under test while changing weights. However, the new system decreases the amount of force applied compared to the air cylinder system by 50 %. Tests show that the amount of force decreased by either system (prior to the nominal force) does not affect hysteresis measurements. This confidence was established originally by running hysteresis data on a device using the original air cylinder design and comparing it to data taken without any snubbers (manually damping). Figure 5 shows a more recent comparison between calibration runs performed using the air bag snubber and the air

cylinder snubber. It shows that there is relatively minor offset between the two systems, well within the bounds of the repeatability uncertainty of the load cell used for this comparison. Although the smaller force applied to the shaft appears irrelevant, it is still important because it approaches a more ideal situation having no force applied to the shaft while changing weights and further improves the confidence of other hysteresis measurements. In addition, the airbag system was incorporated into the current automation system with only a few minor software changes and will work smoothly with any future upgrades to the automation systems.

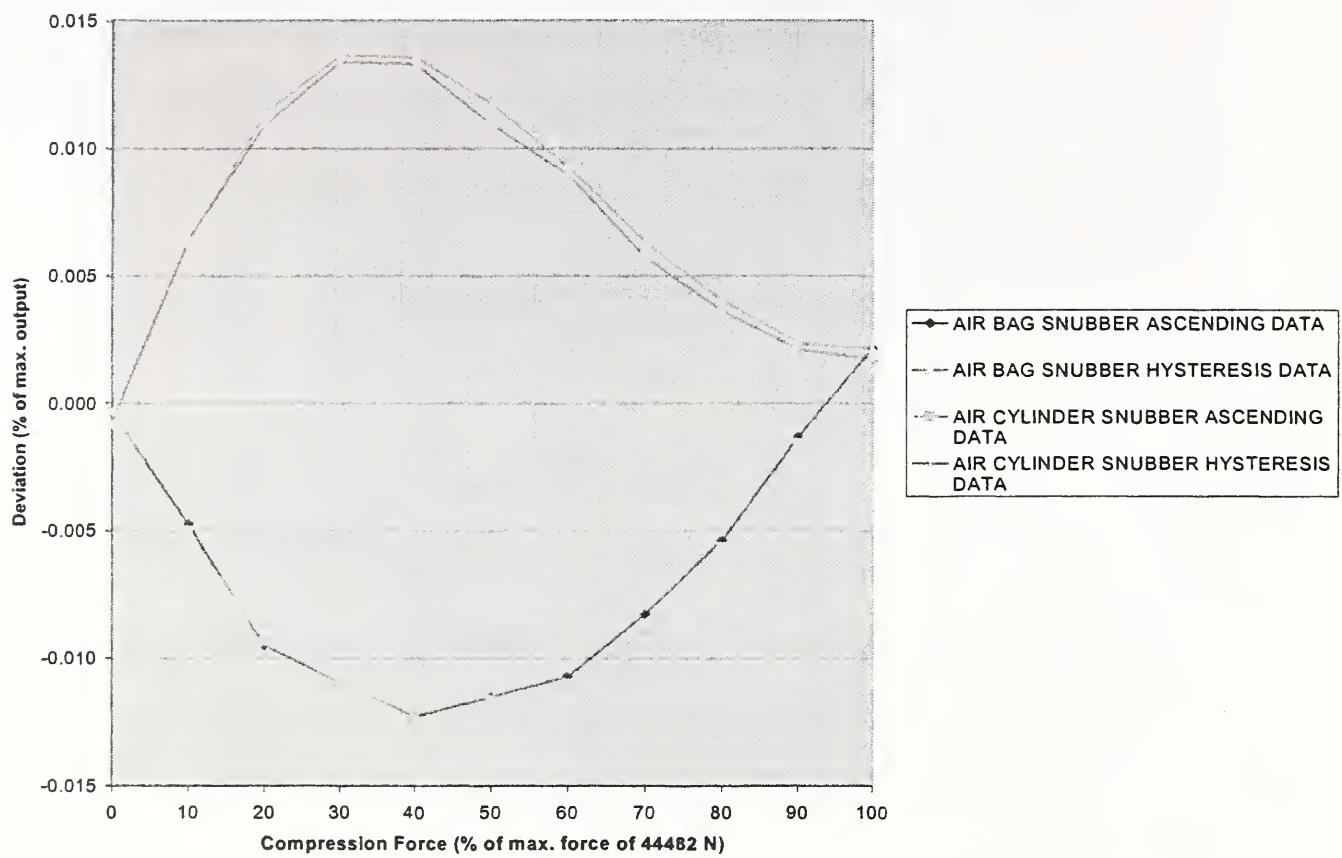


FIGURE 5

**Ascending and Hysteresis Load Cell Data Obtained
Using Different Snubber Systems**

6. Conclusions

The air bag snubbers are a drastic improvement over the original air cylinder snubber design for several reasons. They create a much more stable measurement environment than using the air cylinder snubbers and virtually eliminate the need for extra settling time before taking a measurement using the manual method. The amount of force removed during hysteresis measurements from the unit under test (prior to it experiencing the nominal force) is reduced by a factor of two, improving the confidence in hysteresis measurements. Additionally, the air bag snubbers blend well with current automation systems and are expected to function well with future upgraded automation systems requiring only minor software changes to make it retrofit the existing equipment. With minor design changes, the air bag system will be readily adaptable and is recommended for design and implementation into the 27.1 kN (6100 lbf) dead weight machine. Finally, the design is low cost, low maintenance, and highly effective.

7. References

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5. Morehouse Instrument Company of York, Pennsylvania provided some additional technical and manufacturing support for the air bags used in this project.

